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The U. S. Army Corps of Engineers initiated development of a prototype decimeter defferential GPS positioning system for dredging and gydrographic surveying in 1988. This system is to provi de real-time accuracies better than one decimeter over ranges up to 20 kilometers from a single reference station. A critical feature is to provide the positions in three dimensions to permit enhanced tidal datum determination. The initial stages of the work have been concept development, feasibility studies, and system analyses. The project has recently concentrated on developing a robust technique to resolve ambiguities on-the-fly. Initial results reported in May 1991 are encouraging. Several experiments are currently being conducted to evaluate alternative resolution methods and to quantify operational limitation of the technology.

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DECIMETER POSITIONING FOR DREDGING AND HYDROGRAPHIC SURVEYING

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ABSTRACT

The U.S. Army Corps of Engineers initiated development of a prototype decimeter differential GPS positioning system for dredging and hydrographic surveying in 1988. This system is to provide real-time accuracies better than one decimeter over ranges up to 20 kilometers from a single reference station. A critical feature is to provide the positions in three dimensions to permit enhanced tidal datum determination. The initial stages of the work have been concept development, feasibility studies, and system analyses. The project has recently concentrated on developing a robust technique to resolve ambiguities on-the-fly. Initial results reported in May 1991 are encouraging. Several experiments are currently being conducted to evaluate alternative resolution methods and to quantify operational limitations of the technology.

1 INTRODUCTION

Presently dredges and hydrographic survey vessels are positioned horizontally with systems that electronically measure multiple ranges or ranges and angles from previously established transponder stations on shore. Most require the vessel to occupy a calibration point installed near the job site each work day to either initialize or calibrate the system or to verify its accuracy. Maintaining these shore stations and calibration points, moving transponders, and performing the calibration/verification process are extremely expensive and labor intensive activities. Typical accuracies of three meters are obtained with these systems. In addition, all dredging and survey operations are vertically referenced to a tide, lake, or river gage to reduce the depth readings to some datum, such as mean lower low water (MLLW) in tidal areas. This method assumes that either water surface elevations at the gage site accurately represent the surface elevations at the survey site or some type of zoning model exists to generate corrections. Current technology limits the surveyors' ability to define this datum to an accuracy of about 0.2 meter in many situations. Offshore tide gages are used as a means to produce mathematical models of the surface characteristics of a body of water. However, these are expensive to install, operate and maintain. Furthermore, the models produced are limited in accuracy by various tidal characteristics, as well as meteorological, oceanographic, and hydrological effects.

The U.S. Army Corps of Engineers, under its Dredging Research Program, is developing a GPS-based system to position dredges and hydrographic survey vessels to an accuracy of one decimeter in real-time. The basic design goals for this new system are to increase the operational capability for both horizontal and vertical positioning, to eliminate as many shore-based control stations as possible, and to provide the system at a cost comparable to existing systems. As with all GPS based systems, it will be three-dimensional and operate in all weather conditions, 24 hours per day. The present design schedule calls for delivery of the prototype by September 1993.

2 PROJECT HISTORY

This project began in 1988 as one of the highest priority efforts under the Corps' Dredging Research Program. The first phase of work was to perform an independent feasibility study. This study, conducted by the University of New Brunswick (Wells, 1989), had two primary objectives. The first objective was an industry review to identify any ongoing developmental efforts. The second objective was to determine and describe the technical constraints associated with developing and operating a 0.1 meter accuracy GPS positioning system. The study concluded that such a system had not been developed. Further, the major obstacle to produce a robust system was development of a method for carrier cycle ambiguity resolution without the need of static initialization.

Two field experiments were conducted by the U.S. Army Engineer Topographic Laboratories (USAETL) while the feasibility study was being prepared. These experiments were designed to examine the potential accuracy and suitability of GPS operating on a moving platform. The first test collected GPS phase data from a receiver mounted on a cart traveling along the sled track located at Holloman Air Force Base near Alamogordo, New Mexico (Goad 1989). The sled's position and velocity were also maintained by an independent precise tracking system physically built into the track structure. This experiment showed that with the exception of initial alignment biases of 2 to 3 cm the root mean square (RMS) values are typically less than 1 cm. The second experiment was designed to test the use of existing GPS technology and kinematic techniques to:

- Determine the position of a continuously moving hydrographic survey vessel
- Measure the tide relative to a known datum
- Determine the capaabilities of existing kinematic techniques for hydrographic survey vessel positioning

It was conducted aboard the U.S. Army Corps of Engineers (USACE) survey vessel *Adams* operating on the open waters of the Chesapeake Bay. This test demonstrated that then existing kinematic GPS technology could be used to track the carrier phase and determine the three-dimensional position of a constantly moving hydrographic survey vessel. A bias discovered in the horizontal position indicated that a more reliable truth system must be used for accuracy testing. In the vertical component, relative elevations between GPS and a primary NOAA tide gage agreed at the decimeter level for a 45 minute observation period (Burgess 1990). Both of these experiments relied on a static initialization process to resolve carrier ambiguities.

The second phase of the project concentrated on several studies to define the components required to build a prototype system. These studies included an

investigation of data link alternatives (Enge 1990), a systems analysis (Geier 1990), and an investigation of using GPS to determine tides (Leick 1991). Each of these provided valuable insights related to expected performance, required system components, and unnecessary components. As a result, the basic prototype system will likely comprise:

- C/A code L1/L2 receivers
- rubidium clocks
- VHF/UHF radios
- workstation or 486-compatible computers

During all of the reported work, a significant obstacle was the lack of software for resolving integer ambiguities while one receiver is constantly in motion (on-the-fly). Although we demonstrated that survey vessels could be accurately positioned with GPS by performing a static initialization at the dock, this was not a viable alternative for a robust, operational system. Therefore, early in 1990, work began on developing algorithms to determine integer ambiguities on-the-fly (Remondi 1991).

In this case we rely on the carrier-smoothed code (Hatch 1982) to provide an initial guess to within a few meters (e.g., 2 m for C/A code and 0.5 m for P code). Trial and elimination is used to evaluate candidate positions within a specified volumetric neighborhood of this initial solution. Conceptually, every cubic centimeter within a 4 meter cube could be examined. Initial success is determined if the ambiguities are approximately integer values at all the selected epochs. What ultimately discriminates candidate solutions is the integrated carrier Doppler shift. Given a sufficiently long time span, only the correct starting poition (or, equivalently, the correct lanes) will yield an integrated Doppler history which agrees with the carrier observations.

In practice every cubic centimeter is not evaluated to avoid unnecessary computations. Instead the candidates are selected as the points of intersection of three double-difference planes. The intersection of double-difference planes can be accomplished with a variety of observables. With L1 this process yields a three-dimensional lattice of candidates based on the intersection of 19 cm lanes. Assuming the planes to be perpendicular yields 68,921 candidates in a cube based on +/-3.8 m from the initial guess. This is certainly preferred to evaluating every cubic centimeter since there are 440,711,081 such candidates.

In this investigation dual frequency C/A code receivers were used where the observed L1 wavelength is 19 cm and the observed L2 wavelength is 12.2 cm. The candidates at the defining epoch are generated using L1 (19 cm), L34: L1-L2 (34 cm), L43: 2• L1-L2 (43 cm), and L163: L34-L43 (163 cm). In practice, however, observables formed as differences of raw observations and differences of differences are noisy, complicating this simple presentation. To evaluate the technique a series of data sets were gathered, on land, where the roving receiver could be positioned over known points from time to time. Kinematic GPS <u>with</u> static initialization was used to establish the truth trajectory. Then kinematic GPS <u>without</u> static initialization, as described above, was used to generate all or part of the trajectory. The two trajectories were then compared. Summarizing the results of this work:

- The kinematic on-the-fly resolution method works with five satellites, but, the process is significantly stronger with six.

- Ambiguity resolution was a resounding success over a 0.5 and 1.4 km baseline.
- Ambiguity resolution was sucessful over a 13 km baseline in 17 out of 21 data sub sets, using 5 or 6 satellites for 10 to 97 minutes of data in the 163 cm mode (Remondi 1991).

3 CURRENT ACTIVITIES

In the spring of 1991 we entered a third phase of the project. To properly design and construct the prototype, and to be able to provide realistic guidance to the system user(s), we began a series of evaluation projects to define the operational criteria for operating in the marine environment based upon on-the-fly GPS post-processing software. The questions we will attempt to answer are:

- Can we obtain a vertical accuracy of 0.1 meter, 1 sigma?
- What is the maximum separation distance between receivers to maintain this accuracy?
- How long does it take to resolve ambiguities, at various distances, and with various SV visibility scenarios?
- How much data can be recovered after regaining lock and prior to ambiguity resolution?

In addition to the algorithm development of Dr. Remondi supported by this work, at least two other investigators are working towards a similar goal. They are Dr. Hein, Institute of Astronomical and Physical Geodesy, University of Munich, and Mr. Ron Hatch, Magnavox. To date we have been able to process data with the software developed by Drs. Remondi and Hein.

The field experiments for this evaluation process are described below.

a. First we positioned a moving small boat using a Trimble 4000 SST dual frequency receiver. Every five minutes the antenna on the boat was transferred to a fixed point on a pier. A few epochs were recorded and then the antenna was returned to the boat. The fixed point on the pier had predetermined coordinates and was used as "truth". Five one hour tests were conducted in this manner. Two reference stations were used. One reference station was located near the experiment site for all five tests. This station will be used as another sort of "truth" because the processed trajectories will have good accuracy and can easily resolve ambiguities. The other reference stations were located at a different site for each test. The distance from the boat to this reference station was 5, 10, 15, 20, and 25 kilometers, respectively. Each test lasted a minimum of one hour with at least five satellites continually in view above 10 degrees. The receiver in the boat was NOT subjected to any type of static initialization.

b. In the next test we installed a Trimble 4000 SST dual frequency receiver on a truck that was positioned using the photogrammetric test course located at the United States National Institute of Standards and Technology. The experiment plan required the GPS-mounted truck to pass through the test course while photos are taken of the antenna. The position of the antenna is being computed using photogrammetric techniques. Those positions will then be compared to antenna positions computed using on-the-fly GPS post-processing technology. Each test lasted a minimum of one hour with five satellites continually in view above 10 degrees. The reference station was located at increasing distances from

the course to a maximum of 25 km. This test will be repeated during the last week of September. The photogrammetric technique is nominally considered to be a half-decimeter positioning system.

c. During the last week of August the USACE hydrographic survey vessel *Gilette* was simultaneously positioned with a Trimble 4000 SST dual frequency receiver and a Krupp-Atlas Polarfix positioning system, nominally specified as an 0.5 m horizontal postioning system. The Polarfix positions are being compared to on-the-fly GPS post-processed positions. This comparison will demonstrate how OTF positioning techniques stand up against an operational positioning system within the Corps of Engineers. Two reference stations were located 1 and 4.5 km from the vessel. During the experiment the vessel passed under a bridge to test the ability of on-the-fly GPS post-processing software to recover from gaps in GPS satellite coverage. The test lasted about two hours with five or more satellites continually in view based on an elevation mask of 10 degrees. Static initialization was not used for the moving receiver.

d. On the 10th through 20th of September a mobile ocean going tripod will be simultaneously positioned with a Trimble 4000 SST dual frequency receiver and a Geodimeter range/azimuth system as it moves through the surf. The Geodimeter positions will be compared to the on-the-fly GPS post-processed positions. The Geodimeter is a half-decimeter positioning system. The reference station will be located at increasing distances from the tripod following the same procedures mentioned previously. Each test will last a minimum of one hour with five or more satellites continually in view as based on an elevation mask of 10 degrees. Static initialization will not be used for the moving receiver.

The execution of these field tests and the subsequent data processing and analysis has been an exciting challenge. Some early results have indicated that we must reconsider the experiment designs. It is difficult to fully respect the accuracy potential of GPS. This is complicated by the fact that no system exists today with which to fully compare GPS (three-dimensional/high dynamics) and to sufficiently quantify the operational parameters.

The results are just now beginning to be summarized. As of this writing substantial processing and exciting new results are just coming in, however they are not sufficiently complete to be tabulated in this paper. The results are often at or well below the 0.1 m level of accuracy. Sometimes when the solution appears outside of this limit, investigation shows that the "truth" system is suspect or that processing was not executed correctly. For example, poor satellite geometry can lead to short periods of positioning errors in the many-decimeter realm. As a second example poor satellite geometry can (temporarily) lead to incorrectly mending cycle slips by one or more cycles.

As we collect and process data we no longer ask the question "will it work" but instead we ask "what are the proper operational guidelines."

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